5-2021

Pterion and Broca's Area: An Exploration of Asymmetry in the K-S distance

Bryn R. Dalrymple
bdalrymp@vols.utk.edu

Pterion and Broca's Area: An Exploration of Asymmetry in the K-S Distance

Bryn Dalrymple

University of Tennessee Knoxville

Abstract

This study was done to address a gap in the research regarding the pterion region of the cranium; specifically, the Krotaphion-Sphenion (K-S) distance of pterion. While many studies have been done on the different types of pterion, this study focuses on the K-S distance and compares the left and right sides of 882 crania of Americans of European decent origin in order to see if there was a significant difference between the sides. This is based on the hypothesis that Broca's area makes the left side larger. After taking the measurements, the data was analyzed through a Paired T-test and the distributions were tested for normalcy through the Shapiro-Wilk test. The data shows that there is a significant difference in the sides, and that the left side is larger by roughly a millimeter for both female and male crania though the male crania were larger on average. This supports the hypothesis that there is a left bias, which then supports the hypothesis that Broca's area contributes to the asymmetry of the cranium causing a left bias, though more research should be done to further support the hypothesis.

Intro

The human cranium is variable and asymmetrical, and it has been extensively studied for both medical and forensic applications. Many metrics have been taken of the cranium, and they have been thoroughly documented and compared, but one of the few areas that have not been extensively measured and documented is the pterion region of the cranium, even though it is an important region for neurosurgery. In this study, the pterion region of the left and right sides of crania are measured and analyzed in order to compare them. The aim of this study is to see if the distance between the anterior and posterior points of pterion are larger on the left side of the crania than the right side. One hypothesis is that Broca's area of the brain might impact the measurement of pterion, and since it is on only the left side of the brain, the crania on that side would be impacted more. Analyzing the differences between the left and right sides of the pterion is helpful to further understand the asymmetry of the cranium and whether the differences are significant.

Literature Review

Asymmetry is an important part of anatomy and knowing the asymmetry of the body is very important for doctors specializing in surgery. Asymmetry is found throughout the human body, and the brain is no exception. The left and right hemispheres have different functions so naturally they have slightly different structures. One of those structures is Broca's area, a structure that focuses on the production of language located in the anterior left hemisphere of the brain (Brain Basics 2007). This area of the brain has an analogous structure on the cranium. It is the part known as pterion, and it is a region where the sutures of four bones of the cranium, forming from the Sphenoid fontanelle, meet. It is an important region for neurosurgery, as it is one of the thinnest parts of the cranium (Develi and Mehtiyev 2020, Gray 1995). Some people have focused on measuring pterion, specifically the measurement from the anterior part called Krotaphion to the posterior point called Sphenion (Jellinghaus et al. 2020).

Noting the asymmetry in the hemispheres of the brain was one of the earliest things discovered about the brain, having been noticed in the late 19th century by Broca and Wernicke, who the parts involving language in the left hemisphere were named after (Toga and Thompson 2020, Intelecom 2016). In the posterior temporal-parietal region is Wernicke's area, which focuses on language comprehension. In the lateral posterior two-thirds of the inferior frontal gyrus, which is in the anterior portion of the brain, is Broca's area and it is mainly used for language production. Even sign language is interpreted in those areas, even though previously it was thought that that sign language would be centered in the more visual areas of the brain (Intelecom 2016). As technology has become more advanced, the role of Broca's area has become more defined. It is now thought to act as a processing area regarding grammar, lexicon, and phonology (Sahin et al. 2006), an area to help with syntactic processing, syntactic unification, verbal working memory, plus other multimodal cognitive processes (Rogalsky and Hickok 2011, Hagoort 2005), and also an area that helps as a prearticulatory stage with word production-- acting as an intermediary forwarding information across large networks involving the superior temporal gyrus and the premotor and motor cortexes (Flinker 2015). Certain aspects of how Broca's area works in sentence comprehension are still unknown, but it is known that it is an important area regarding language.

The analogous structure to Broca's area on the cranium is the pterion. However, pterion also has many other uses, especially in surgery. Pterion is a region where four bones in the cranium meet: the frontal, parietal, temporal, and sphenoid. These usually form an 'H' shape, although there are three other types that have been recorded since Murphy documented them in 1956 (Murphy 1956). The types of pterion are called the Spheno-Parietal, which is the classic 'H' shape where the sphenoid and parietal meet, the Fronto-Temporal, where the frontal and temporal meet, the stellate, the 'K' shape where the bones all meet at one point, and the epipteric, where there is one or more extra bones found in between the four so that they do not meet. Pterion is very close to Broca's area as well as the middle meningeal artery and the Sylvian fissure, and it has been used for keyhole surgeries and tumor resections (Grey 1995, Yuvaraj, Thenmozhi, & Sriram 2015, Kalthur et al. 2017, Rathnakar et al. 2019). It is also important because it gives access to the middle and anterior fossae, the suprasellar and parasellar structures near those fossae, and the circle of Willis in the circulatory system (Uz et al 2020). Because pterion gives so much access to important parts of the brain, the pterional approach is one of the most common transcranial approaches used in neurosurgery and has been used since Yasargil et al. popularized it in 1976.

Most of the studies done featuring pterion have been about the percentages of the types of pterion in crania of differing populations (Saxena, S., Jain, S., & Chowdhary 1988, Natekar, DeSouza, & Natekar 2011, Chaijaroonkhanarak et al. 2017, Kalthur et al. 2017, Rathnakar et al. 2019, Develi, and Mehtiyev 2020). This is mainly because of the surgical aspects, and because the epipteric types, though not as common, can confuse surgeons because they look like fractures (Kalthur et al. 2017). The most common type has been the Spheno-Parietal, or H shape. A few other studies have tried to measure pterion with some focusing on bilateral symmetry of the types (Kalthur et al. 2017, Rafi, Sayeed, & Anwar 2020), and others focusing on the distance between the anterior point Krotaphion and the posterior point called

Sphenion for sex and ancestry determination (Jellinghaus et al. 2020). Other studies focusing on analyzing the Krotaphion-Sphenion distance are rare.

Pterion is an important region on the cranium because it is used for neurosurgery, and because it is outside of Broca's area in the brain. It has been studied for a long time, but the studies have focused on the types of pterion, as that is what it has been used for. Not very many studies have looked to measure pterion through the Krotaphion-Sphenion distance. The Jellinghaus et al. (2020) study found a left bias in both males and females in their study, but that was not the main focus. The aim of this study will be to test the hypothesis that there is a left bias.

Materials and Methods

The data come from crania from the Forensic Anthropology Databank (FDB). The FDB started in 1986 with a grant from the National Institute of Justice and contains extensive demographic information for many cases. The skeletal information within the FDB includes cranial and postcranial metrics (Forensic anthropology Data Bank). The dataset is comprised of 574 male and 329 female crania of Americans of European descent, for a total of 903. There were twenty-one outliers, which were found using the Tukey's fences method with a k of 1.5 and were removed from the data, leaving 882 total crania, with 324 of them being female and 558 male.

The sample is made up of donated and forensic cases from UTK and other institutions. Crania that do not have a measurable K-S distance, such as those with an epipteric bone or with fronto-temporal articulation, were omitted from the sample. The crania in the FDB are digitized with a Microscribe digitizer using software called 3skull created by Steve Ousley (Statsmachine Software, 2020). The sample was measured in millimeters (mm). The K-S distance was provided by Prof. R. Jantz and was calculated by taking the x, y, and z coordinates produced by the digitizer and then using the Pythagorean theorem. The differences between each coordinate were recorded, squared, added together, and then the square root was taken in the equation provided below.

$$\text{Distance} = \sqrt{((x2 - x1)^2 + (y2 - y1)^2 + (z2 - z1)^2)}$$

The female and male crania were analyzed separately, and then the sexes were pooled. The means and standard deviations of the left and right K-S distances were calculated, and then a paired t-test was run. The null hypothesis of the t-test is that the means of the left and right K-S distances are equal. The alternate hypothesis is that they are not equal. μ1 is the left side μ2 is the right side.

$$H_0: \mu_1 = \mu_2$$

$$H_1: \mu_2 \neq \mu_2$$

Paired t-tests are used to compare the means of two sets of data to see if they are different; usually this is used to see if there is a difference between matched pairs. This time, it was used since the left and right sides of the same crania were compared. The T-values were found using the paired t-test, and the values were used to compute the P-values.

Shapiro-Wilk tests were conducted to test if the sample comes from a normal distribution.

Results

Comparing the mean values of the left and right Krotaphion-Sphenion distance, a statistically significant difference exists in the left and right sides of the crania with the left sides, on average, being larger. Table 1 contains the means and standard deviations of the female, male, and pooled K-S distances. The female crania have smaller K-S distances on average, but the female crania also have more variation. Table 2 shows the means and standard deviations of the differences between the female, male, and pooled left and right sides of the crania. The average difference between the left and right side was larger for female crania than male crania, but the variation was greater on the male crania by a small margin. The average difference between the left and right K-S distances in the pooled sample was 0. 9382 mm.

TABLE 1. Comparison of mean and standard deviation values of Krotaphion-Sphenion distances of left and right sides in the crania (in mm).

	Mean K-S distance Left (in mm).	Mean K-S distance Right (in mm).	Standard Deviation K-S distance Left	Standard Deviation K-S distance Right
Female	14.250	13.198	4.804	4.507
Male	15.200	14.328	4.328	4.370
Pooled	14.851	13.913	4.530	4.452

TABLE 2. Comparison of mean and standard deviation values of the difference between Krotaphion-Sphenion distances on left and right sides in the crania, subtracting the right from the left (in mm).

	Mean K-S difference left minus right (in mm).	Standard Deviation of difference
Female	1.051	3.934
Male	0.873	4.049
Pooled	0.938	4.006

To further investigate the differences, two-tailed T-tests were performed on the female, male, and pooled data, and the P-values and T-values can be found in Table 3. For the pooled test, the T-value was -6.956, and the P-value was 6.812 E-12, which is smaller than the error probability of 0.05, meaning that the difference in the K-S distances between the left and right sides of the crania were statistically significant. The female and male two-tailed T-tests also had P-values less than 0.05, so the differences between the left and right K-S distances are also statistically significant as well.

TABLE 3. Comparison of the P-Values and T-Values from the 2-tailed T-test.

	2-tailed P-Value	T-Value
Female	2.310 E-06	-4.811
Male	4.886 E-07	-5.091
Pooled	6.812 E-12	-6.956

The results of using the Shapiro-Wilk test for normal distribution are shown in Table 4. The left side of the crania, female, male, and pooled, all had P-values greater than 0.05, so they were found to be normally distributed. The right side of the male crania also had a P-value greater than 0.05, so it was found to be normally distributed as well. The P-values for both the female and pooled right sides were less than 0.05, so the distribution of those populations differed from a normal distribution. They were also skewed to the right.

TABLE 4. Comparison of the left and right P-Values from the Shapiro-Wilk test for normal distribution of the Krotaphion-Sphenion distances.

	Left P-value from Shapiro-Wilk Test	Right P-value from Shapiro-Wilk Test
Female	0.1295	0.0031
Male	0.5421	0.1081
Pooled	0.2292	0.0020

Discussion

In this study, the left and right K-S distances were compared within a single population sample of 882 Euro-American crania after the outliers were removed. The analysis was to see if there was a marked difference between the left and right K-S distances on the crania within the population. Jellinghaus et al. (2020) found a difference in the left and right sides of the crania that they examined, however that was not the purpose of their study. This study expands upon that with a larger population of Euro-Americans.

Left and Right differences

The examined K-S distance showed a difference in the left and right sides of the crania. The results of the paired T-test show a statistically significant difference between the left and right sides with a P-value of 6.812 E-12. On average, the left side was 14.851 mm and the right side was 13.913 mm, a difference of nearly an entire millimeter. The male crania, on average, were larger than the female crania on both sides, however the female crania showed a larger difference in the left and right sides than the males, with the female left side being 1.051 mm larger than the right and the male being 0.873 mm larger. The left and right measurements of the female crania also showed more variability than the male left and right sides, as the standard deviations are larger. This asymmetry supports the hypothesis that the asymmetry of the cranium reflects the asymmetry of the brain with regard to Broca's area.

Comparison to Jellinghaus et al. (2020)

Like Jellinghaus et al. (2020), the male crania were found to have a larger K-S distance for both the left and right sides of the crania, and the right side was found to be smaller overall. This study did not test specifically for differences in sexes, however Jellinghaus et al. (2020) did. They found that there was a statistically significant difference between male and female crania, with the male crania being larger on average, which is consistent with this study, as well as the general assumption that male crania are larger than female crania.

Like Jellinghaus et al. (2020), this study did not use all the variants of pterion, and instead only used the Spheno-Parietal type, as it has a measurable K-S distance, and it is the most commonly found type (Murphy, T. 1956, Saxena, S., Jain, S., & Chowdhary 1988, Natekar, DeSouza, & Natekar 2011, Chaijaroonkhanarak et al. 2017, Kalthur et al. 2017, Rathnakar et al. 2019, Develi, and Mehtiyev 2020, Rafi, A., Sayeed, S., & Anwar, M. 2020). Unlike Jellinghaus et al. (2020), this study did not have as diverse a sample, as Jellinghaus et al. examined four different populations: African-American, Euro-American, German, and Rwandan.

Call for research

This study only used measurements of the Spheno-Parietal type of pterion, which leaves out some of the population. A future study comparing the left and right sides of the other measurable variants would be useful. This study also mainly looked at crania of Euro-American origin, so a more diverse sample would be better to get more complete results. Since the left sides of the crania are larger, that correlates with Broca's area in the brain, as that area is near pterion but only the left side; however more research needs to be conducted before anything is conclusive. One way to do this would be to use CT scans of people and measure both pterion and Broca's area, then compare the sizes of them to see if larger K-S distances are found on crania with a larger Broca's area.

Conclusion

The crania and the brain are complex and asymmetrical and require vast amounts of research in order to be better understood. Though the pterion region is important for surgery, it has not been studied as much as other parts of the cranium. The aim of this study was to analyze the K-S distance and compare the left and right sides to see if there was a significant difference between them. In this study the metrics of 882 crania were analyzed for differences in the right and left measurements of the K-S distance, and they were further broken down to observe the differences between the sexes. Between the sexes, the male crania had a larger K-S distance in general, but the difference between the left and right sides was larger in the female crania. The T-test found that there is a significant difference between the right and left K-S distances of the pterion, with the left side being larger by almost a millimeter. The larger left side supports the hypothesis that the asymmetry reflects Broca's area. Further research should be done to support the hypothesis further, as there was a limitation in this study which comes from the crania in the sample all being of Euro-American origin. Another study with a more diverse sample would be able to see if the difference between the left and right sides of the crania is consistent across populations and address any differences. One form of research to corroborate the findings of this study would be to compare the size of Broca's area to the K-S distance through CT scanning to see if there is a correlation. Since other factors must contribute to the asymmetry, further research should be done to examine what other variables could contribute to this asymmetry, such as human variation, external environmental factors, and ancestry. Understanding the differences between the sides will aid in further understanding the asymmetry of the body and a first step to understanding the relationship between the crania and the brain.

References

Available Light Productions (Producer), & . (2007). Brain basics. [Video/DVD] Teachers TV/UK Department of Education. Retrieved from https://video-alexanderstreet-com.proxy.lib.utk.edu/watch/brain-basics

Chaijaroonkhanarak, W., Woraputtaporn, W., Prachaney, P., Amarttayakong, P., Khamanarong, K., Pannangrong, W., Welbat, J. U., & Iamsaard, S. (2017, December). Classification and Incidence of Pterion Patterns of Thai Skulls/ Clasificacion e Incidencia de los Patrones de Pterion en Craneos de Tailandia. *International Journal of Morphology*, *35*(4), 1239+. https://link.gale.com/apps/doc/A530828583/AONE?u=tel_a_utl&sid=AONE&xid=edbe02d5

Develi, S., Mehtiyev, R. (2020). Inner Surface of Pterion in Terms of Surgical Approaches: An Anatomical Cadaveric Study. Bezmialem Science, 8(1), 26–30. https://doi.org/10.14235/bas.galenos.2019.2493

Flinker, K. (2015). Redefining the role of Broca's area in speech. Proceedings of the National Academy of Sciences - PNAS, 112(9), 2871–2875. https://doi.org/10.1073/pnas.1414491112

Forensic anthropology Data Bank (FDB). (n.d.). Retrieved January 27, 2021, from https://fac.utk.edu/background/

Gray H, Williams PL, Bannister LH (1995) Gray's anatomy: the anatomical basis of medicine and surgery. Churchill Livingstone, New York

Hagoort, P. (2005) On Broca, brain, and binding: A new framework. *Trends Cogn Sci* 9(9):416–423. https://doi.org/10.1016/j.tics.2005.07.004

Jellinghaus, K., Matin, S., Urban, P., Bohnert, M., & Jantz, R. (2020) Study of the K-S distance on skulls from different modern populations for sex and ancestry determination. *Rechtsmedizin* **30,** 451–457. https://doi.org/10.1007/s00194-020-00426-9

Kalthur, S. G., Vangara, S. V., Kiruba, L., Dsouza, A. S., & Gupta, C. (2017). Metrical and non-metrical study of the pterion in South Indian adult dry skulls with notes on its clinical importance. *Marmara Medical Journal*, *30*(1), 30–39. https://doi.org/10.5472/marumj.299387

Murphy, T. (1956). The pterion in the Australian aborigine. - Amer. J. Phys. Anthrop. 14, 225-244. https://doi.org/10.1002/ajpa.1330140218

Natekar, P., DeSouza, F., & Natekar, S. (2011). Pterion: An anatomical variation and surgical landmark. Indian Journal of Otology, 17(2), 83+. https://doi.org/10.4103/0971-7749.91045

Rafi, A., Sayeed, S., & Anwar, M. (2020). Cranial CT scan evaluation of morphological variations and location of pterion in Pakistani male population for lateral neurosurgical approach. *Pakistan Journal of Medical Sciences*, *36*(3), 310–315. https://doi.org/10.12669/pjms.36.3.2003

Rathnakar, P., Vinod, R., Swathi, & Sinha, A. (2019). Anthropometric Evaluation of Pterion in Dry Human Skulls Found in Southern India. *Journal of Evolution of Medical and Dental Sciences*, *8*(31), 2475+. https://doi.org/10.14260/jemds/2019/541

Rogalsky, H. (2011). The role of Broca’s area in sentence comprehension. Journal of Cognitive Neuroscience, 23(7), 1664–1680. https://doi.org/10.1162/jocn.2010.21530

Sahin, N. T., Pinker, S., Cash, S. S., Schomer, D., & Halgren, E. (2009). Sequential Processing of Lexical, Grammatical, and Phonological Information Within Broca's Area. *Science*, *326*(5951), 445–449. https://doi.org/10.1126/science.1174481

Saxena, S., Jain, S., & Chowdhary, D. (1988). A comparative study of pterion formation and its variations in the skulls of Nigerians and Indians. *Anthropologischer Anzeiger*, 46(1), 75–82. https://doi.org/10.1127/anthranz/46/1988/75

Statsmachine software (2020). Retrieved January 29, 2021, from http://statsmachine.net/software/

Toga, A., Thompson, P. Mapping brain asymmetry. *Nat Rev Neurosci* **4,** 37–48 (2003). https://doi.org/10.1038/nrn1009

Uz, A., Korkmaz A., Filgueira, L., Guner, M., Tubbs, R., & Demirciler, A. (2020). Anatomic Analysis of the Internal and External Aspects of the Pterion. *World Neurosurgery*, 137, 84–88. https://doi.org/10.1016/j.wneu.2020.01.198

Yuvaraj, S., Thenmozhi, & Sriram, N. (2015). Pterion: An Important Landmark for Neurosurgery. *Research Journal of Pharmacy and Technology*, 8(8), 1153–1154. https://doi.org/10.5958/0974-360X.2015.00206.1

Yasargil, M.G., Antic, J., Laciga, R., Jain, K. K., Hodosh, R.M., & Smith R.D. (1976) Microsurgical pterional approach to aneurysms of the basilar bifurcation. S*urgical Neurology*, 6 (2), pp. 83-91